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## **KAON YIELDS FOR 2 TO 8 GEV PROTON BEAMS\*<sup>†</sup>**

K.K. GUDIMA, N.V. MOKHOV, S.I. STRIGANOV

*Fermilab, MS 220, P.O. Box 500  
Batavia, IL 60510, U.S.A.*

### **Abstract**

Production rates of kaons and accompanying particles from nuclear targets are modeled with LAQGSM and MARS15 for low-energy proton beams.

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## KAON YIELDS FOR 2 TO 8 GEV PROTON BEAMS

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### 1. Introduction

The next generation of rare-decay experiments – to operate at the intensity frontier – requires kaon beams of extraordinary quality. The proton kinetic beam energy ( $T_p$ ) threshold for producing kaons is 1.7 GeV (on protons) and the kaon yield fraction grows with the increasing number of exclusive production channels that open and saturate around  $T_p$  of 6 GeV. The research potential of recently proposed accelerator architecture at Fermilab, which is based on a 2-GeV CW proton linac, turns to be very high [1]. It is strongly linked to energy dependence of kaon production rates in this near-threshold region. The rates of kaons and accompanying particles from light nuclear targets at  $T_p < 10$  GeV are studied in this paper with the improved LAQGSM/MARS15 codes.

### 2. LAQGSM Event Generator

The Los Alamos Quark-Gluon String Model code (LAQGSM) [2] is an improved version of the time-dependent Dubna intranuclear Cascade Model, combined with isobar model at  $E < 4.5$  GeV and Quark Gluon String Model (QGSM) for elementary interactions inside nucleus at  $E > 4.5$  GeV, coupled with the Fermi breakup, coalescence and generalized evaporation-fission models. It has recently been enhanced in the intermediate 2 to 8 GeV region of interest for the Project X experiments. It is used in the MARS15 code [3] for photon, hadron and heavy-ion projectiles at a few MeV/A to about a few TeV/A, providing a

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<sup>‡</sup> Visiting from Institute of Applied Physics, Academy of Sciences of Moldova.

<sup>†</sup> E-mail: mokhov@fnal.gov

power of full theoretically consistent modeling of exclusive and inclusive distributions of secondary particles, spallation, fission, and fragmentation products in realistic experimental setups. In the LAQGSM code,  $K$ ,  $\Lambda$ , and  $\Sigma$  are produced via all meson-baryon (MB) and baryon-baryon (BB) interactions. With a focus on low- $Z$  targets in this study, special efforts were put on model improvements in case of a deuterium target. The momentum distribution of nucleons inside deuteron is taken in the form  $N(q)dq = Cq^2dq/[\alpha^2 + q^2]^\beta$ , fitting experimental data.

### 3. Benchmarking

The code predictions on kaon production in the near-threshold region on deuterium and carbon targets have been benchmarked against experimental data from the ANKE spectrometer at COSY-Julich [4]. The results are shown in Fig. 1 with absolute predictions by LAQGSM. The agreement is amazingly good.

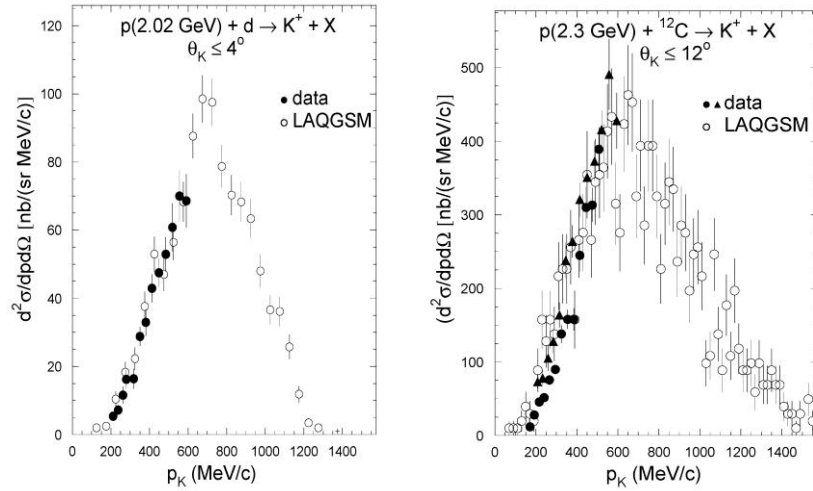


Figure 1. Double differential cross sections of produced  $K^+$  mesons in interactions of protons with deuterium (left) and carbon (right) nuclei.

### 4. Kaon Production Optimization

LAQGSM calculations reveal that in pp and pA interactions, meson and hyperon yields  $Y$  grow rapidly with proton energy  $T_p$  starting from the threshold energies to a transition energy of about 2 GeV (pions) and 6 GeV (kaons and hyperons), slowing down at higher energies and reaching a logarithmic growing mode at

about 12-15 GeV. As a result, the yield over proton energy,  $Y/T_p$ , has a broad maximum at the above transition energies. The kaon yield fraction grows with  $T_p$  and saturates at  $T_p \sim 6$  GeV. Fig. 2 shows energy dependence of  $Y/T_p$  for a carbon target and for various angular and momentum regions of interest for the kaon program [1]. It was also found that at the considered  $T_p$ , the yield of kaons with momentum  $p > 0.3-0.4$  GeV/c is higher from low-Z targets. At the same time, the Fermi-motion in nuclei makes the kaon production threshold energy lower compared to the hydrogen's one of 1.7 GeV. As found in MARS15(LAQGSM) calculations for the case considered, the appropriate target materials range from deuterium to carbon and the effect of secondary interactions in a thick target is rather minor.

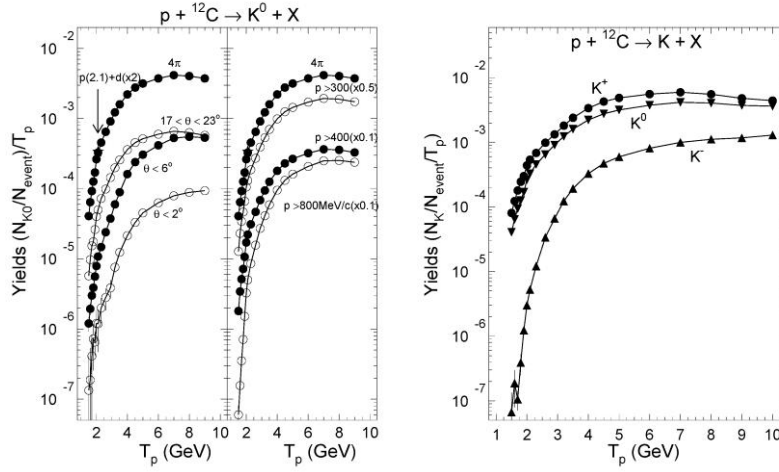


Figure 2. Energy dependence of kaon yields per incident proton kinetic energy  $T_p$  for different angle and momentum windows (left) and total yields of kaons (right) produced by proton in carbon target.

The  $K^+$  and  $K^0$  yields become quite interesting at beam energy  $T_p \sim 2$  GeV, while a modest increase of proton energy to  $T_p \sim 2.5$  GeV makes the entire kaon program – from a particle production standpoint – definitely feasible. Some loss in the  $Y/T_p$  ratio from not going to a higher energy of 5-6 GeV can easily be compensated by a beam power of the CW linac [1].

Momentum and angular distributions of kaons, pions and neutrons generated on a deuterium target by a 3-GeV proton beam are shown in Fig. 3. Neutral kaon distributions coincide with those for  $K^+$  (not the case for hydrogen target), while

anti- $K^0$  yield is 20-30 times lower. There are practically no angular dependence of the kaon momentum distributions at  $\theta < 15^\circ$  at  $T_p < 3$  GeV, while it is quite substantial at higher proton energies. At  $T_p = 8$  GeV, the  $K^0$  yields on a deuterium target are slightly lower than the  $K^+$  ones and the anti- $K^0$  yield is at a 30% level of those for  $K^+$  and  $K^0$ . These results, generated with MARS15(LAQGSM), can be used in designing the experimental setup and planning the experiment.

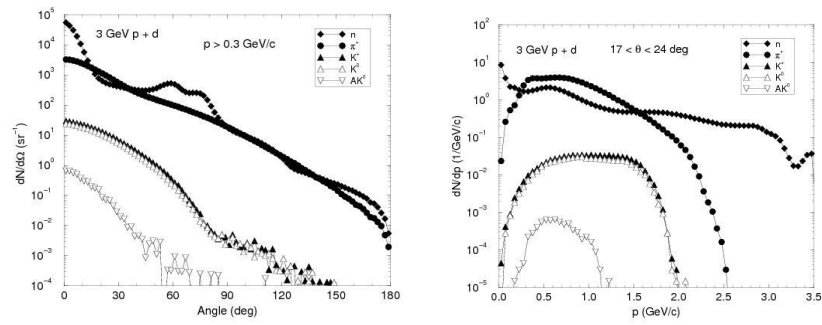


Figure 3. Neutron, pion and kaon angular (left) and momentum (right) distributions calculated with MARS15(LAQGSM) for 3-GeV proton-deuteron inelastic interactions.

## References

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